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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 61 New Cavendish Street, London, W.1, on 2 March 1960, the Chair being taken by C. M. Vignoles, C.B.E., President of the Institute.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record.

The President introduced M. Estavoyer, who then presented the following paper in summary.

CORROSION PROBLEMS AT LACQ SOUR GAS FIELD*

By MICHEL ESTAVOYER†

INTRODUCTION

THE Société Nationale des Pétroles d'Aquitaine (SNPA) discovered the Lacq field in December 1951 following the drilling of Lacq 3. As soon as the gas was observed all possible steps were taken to control the well. However, within a few days, the drill pipe, the $6\frac{5}{8}$-inch casing, then the $9\frac{5}{8}$-inch casing failed because of the corrosive action of the gas, which proved to contain a high percentage of H_2S. It was then that a blowout occurred. It took no less than two months to bring the well under control, during which time the lives of many inhabitants in surrounding villages were in danger (Fig 1).

The Lacq reservoir is characterized by the severe conditions encountered. In addition to 74 per cent of methane, this gas contains 15 per cent of H_2S, 9 per cent of CO_2, 25 g of gasoline/cu m, and 10 g of water/cu m. The depth of the wells varies from 3500 to 5250 m. The bottom hole pressure is at the present time 652 kg/sq cm at a depth of 3700 m. The closed-in wellhead pressure is 507 kg/sq cm. The bottom hole temperature is around 130° C. Production from these wells is generally high. For example, Lacq 120 produces one million cu m/day with a wellhead pressure and temperature of 420 kg/sq cm and 90° C respectively for a bottom hole pressure drop of only 5 kg/sq cm.

In 1951 the problem of equipping the Lacq wells seemed extremely difficult. Few sour gas fields in the world were in production at that time. In any case, none of them had such severe conditions as those of Lacq. Assisted by works published in the U.S.A. at that time, and thanks to the assistance of certain French specialists, the SNPA were able to solve this important problem. To-day, 25 wells have been drilled and equipped. The proved and recuperable reserves amount to 160 milliards cu m. Thus Lacq

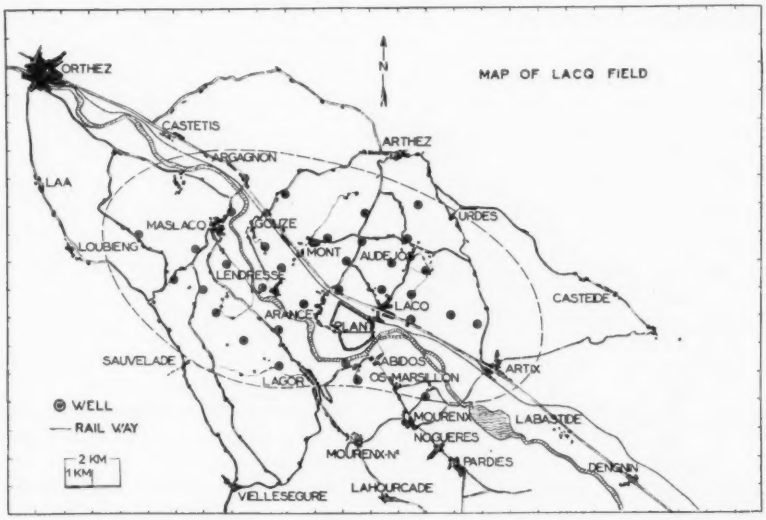

FIG 1

* MS received 8 January 1960.

† Société Nationale des Pétroles d'Aquitaine.

represents a very important source of energy and raw material for France.

In December 1959 Lacq had already produced 3·16 milliards cu m. Production and industrial treatment started in April 1957 at the rate of one million cu m/day. The daily capacity is now 10 million cu m and will reach 20 million in 1961.

In this paper an attempt is made to show how corrosion problems have influenced the design of production equipment at Lacq field. A balance sheet showing the behaviour of the installations with regard to corrosion after two years exploitation will be drawn up; it will be seen how these results affect the improvement of the equipment.

THE DESIGN OF THE INITIAL PRODUCTION INSTALLATIONS AT LACQ AS REGARDS CORROSION PHENOMENA

No detailed description will be given of the production installations at Lacq, as this work has already appeared in other publications. Emphasis will be laid only on those parts of the installations which have an important function in respect to corrosion protection.

The detailed processes of corrosion phenomena in the presence of sour gas in general, and of Lacq gas in particular, will not be recalled. Several French authors, in particular M. Cauchois, Technical Adviser to the SNPA management, have published numerous papers on this subject. It will simply be stated that corrosion in the presence of sour gas may be considered as two connected phenomena, but very different as regards their consequences:

(1) The sulphide stress corrosion phenomena which results both from stress cracking phenomena and from embrittlement. In certain circumstances these phenomena cause sudden failures.

(2) The general corrosion phenomena or the electrochemical dissolving of the metal which appear in the form of pitting or large craters.

The gas from the formation is produced through a tubing. There is a pressure drop at the wellhead which reduces the pressure to about 350 kg/sq cm before entering the flow line installations. In these surface installations there is a further pressure drop at the entrance to the indirect heater; the water accompanying the gas is then separated out and the gas is sent through the pipeline after the injection of an antihydrate and corrosion inhibitor. The materials used at these different stages will be mentioned later.

The Tubing

This is the most important part of the well. The experiences of drill pipe failures on Lacq 3 showed the importance of the sulphide stress corrosion cracking phenomena. It was chiefly to combat this type of corrosion that precautions were taken in three different ways: the nature of the steel, the conditions in which the tubing is used, and the safety devices (Fig 2).

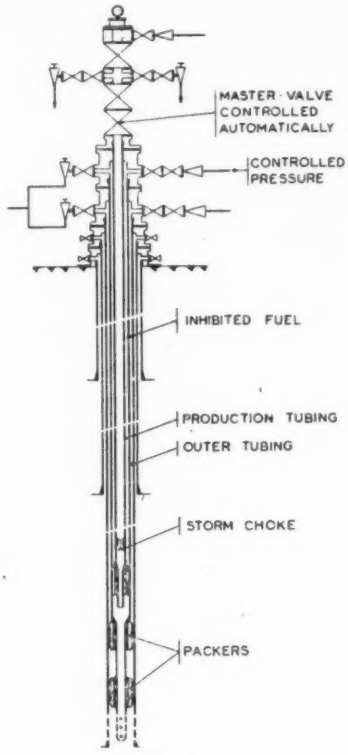

FIG 2
THE EQUIPMENT OF A LACQ WELL

Special steel for tubings were developed in France by the SNPA in collaboration with several metallurgists and pipe manufacturers. Part of the results of these studies have already been published. Three types of steel were then chosen by the SNPA: APS 10M4, of the Acieries de Pompey, 2·2 FOV, of the Forges & Ateliers du Creusot, and MOVP, of the Compagnie des Ateliers & Forges de la Loire. These steels have mechanical properties similar to those of the classical N. 80 grade, *i.e.* a yield strength greater than 56 kg/sq mm. They contain 2 per cent chromium and small quantities of Mo and V. Only the APS 10M4 contains a small percentage of aluminium. The heat treatment given consists of quenching and tempering at high temperature, giving a finely divided metallographic structure which is not to any extent subject to corrosion under tension. The great depth of these wells would not permit the use of the usual size of tubing in the J. 55 grade. Nevertheless, a specially tempered grade J. 55 tubing has been developed

which is undergoing tests in one of the shallower wells on Lacq field.

The conditions in which the tubings were employed were adapted so as to reduce to a minimum the chances of embrittlement failures. It was chiefly towards a limitation of the tensile stress that our efforts were concentrated. The lower part of the tubing is set on a packer so that the maximum residual tensile stress in the tubing head does not exceed 50 per cent of the yield strength.

The bursting pressure at the bottom of the tubing is reduced by setting off the internal pressure of the gas by the pressure of a column of fuel outside the tubing assisted by adjustable pressure from the surface. The tensile stress of the metal in these conditions does not exceed a small percentage of the yield strength.

At the same time was developed, with the French pipe manufacturers, a special joint giving an effective seal for a long period in order to prevent any gas leaks which might have serious effects on the production casing. This Lacq type joint was partly based on an Hydril design.

When the wells are on production, the inner tubing is periodically inhibited. Various methods are employed, the most rudimentary of which consists of dropping six sticks of inhibitor down the well once a month. However, batching every two months with a 10 per cent solution of inhibitor in fuel is preferred.

Various safety systems ensure the control of the wells in case of any failure of the inner tubing. First of all, the latter is set inside a second concentric tubing which protects the well if there is a failure in the inner tubing, and allows for an easy replacement of the production tubing. It is manufactured from a "limited" N. 80 grade steel and the annular space is filled with inhibited fuel capable of protecting the N. 80 against embrittlement by H_2S.

Various types of safety valves ensure the closing-in of the well in case of failure of the inner tubing. At the bottom a safety valve (or storm choke) automatically closes when production rate exceeds a certain fixed value. On the Christmas tree the master valve is controlled automatically. Generally speaking, these security devices are specially made of stainless steel or Monel, in order to maintain the sealing surfaces in good condition. The springs are made of Inconel.

Wellheads

The principal parts of the wellheads are the master valves. Here also it was necessary to limit to a maximum the tensile stress in the steel. For a closed-in wellhead pressure of 540 kg/sq cm the valves used are of the 2900 series, capable therefore of a maximum working pressure of 700 kg/sq cm.

The steels of the first valves were those currently found on the market, *i.e.* either a low molybdenum carbon steel or a 12 per cent chromium steel. These types were not used for any length of time.

Surface Installations and Gathering System

Embrittlement by H_2S seemed to be the principal corrosion factor in the tubing. In the gathering system the presence of water added a second danger, that of general corrosion of the metal. It was with these two aspects of corrosion in view that an endeavour was made, on the one hand, to reduce the tensile stress of the metal to a value of less than 60 per cent of the yield strength and, on the other hand, to eliminate the water, or render its action less severe.

After two pressure drops, one on the Christmas tree, the other at the entrance to the indirect heater, the gas reaches the water knock-out at a maximum pressure of 130 kg/sq cm (Fig 3). Of the 10 g of water

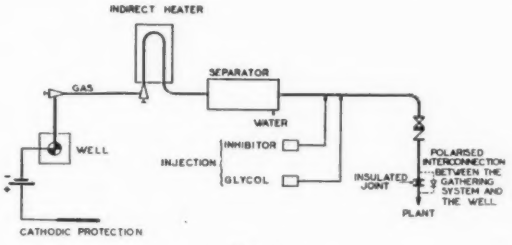

FIG 3
FLOW LINE INSTALLATION

contained in every cu m of gas, 8 g are eliminated by separation; the other 2 g, partly in the form of liquid and partly vapour, remain in the gas and the gasoline. This mixture flows through the gathering system to the plant. Before passing into the gathering system after separation, about 30 litres of an organic corrosion inhibitor are injected for every million cu m of gas, as well as a variable quantity of diethylene glycol and an anti-hydrate agent (from 0·5 to 1 litre for 1000 cu m according to circumstances). All the steels of the material used for these installations are low molybdenum carbon steel. The steel used for the flow lines is grade B. The tensile stress is always less than 60 per cent of the yield strength for a maximum working pressure.

The gathering system is made up of 4-, 6-, and 8-inch pipe linking the wells to the plant. This pipe is of the drawn, seamless, grade B type steel. The welding of the pipe is effected with standardized electrodes. Each well is annealed at 650° C for 20 minutes; it is then carefully inspected by gamma-ray. At maximum working pressure, *i.e.* 130 kg/sq cm, the tensile stress in the pipe, compared with the minimum thickness once the 2 mm extra thickness for corrosion has been deducted, remains less than 52 per cent of the yield strength. It does not exceed 40 per cent of the yield strength at normal working pressure.

The longitudinal section of the gathering system lines is made up of a succession of continuous slopes ending in low points where water evacuation devices are installed.

Numerous safety devices (Fig 4) are spaced out along the gathering system between the wells and the plant. The system is divided into sections isolated by valves and non-return valves which close in the case of a pipe failure, thus reducing to a very slight volume the gas escaping. Whenever the pipe passes

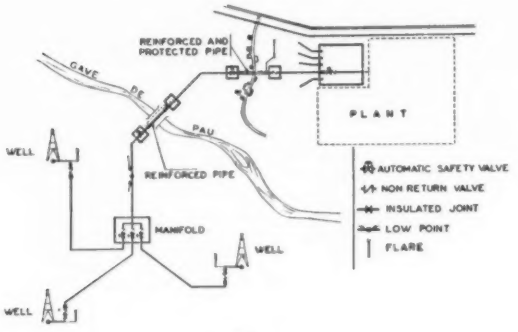

FIG 4

A TYPICAL SECTION OF GATHERING SYSTEM

through a village it is protected by a concentric pipe filled with nitrogen which evacuates the gas to a flare situated at some distance from any houses, should there be any failure in the line. There are also devices for limiting pressures.

BEHAVIOUR OF THE INSTALLATIONS DURING THE FIRST YEARS OF EXPLOITATION

The first production flow tests over a long period of time were made on one well, Lacq 104, which was put on production in May 1956. By 2 March 1957 it had already produced 51 million cu m. It was then that work started on the first unit of the plant, capable of treating one million cu m/day. On 15 July 1958 the capacity of the plant increased from one million to 4 million cu m/day, and in September 1959 it was 9 million cu m/day. Its capacity will reach 15 million in May 1960, and 20 million cu m/day at the beginning of 1961. By 15 December 1959 Lacq field had produced 3105 million cu m of sour gas.

The decisive tests on the materials were carried out at Lacq 104. In addition to tests on the equipment installed on the well, others were made on different materials placed in an experimental device situated downstream from the well.

Since 1 April 1957, the date when the first wells flowed to the gas treatment plant, many practical results have completed the data found experimentally.

In the following sections details of the results of tests on samples, the means of control of the production equipment, and the behaviour of this equipment will be given.

Experimental Devices at Lacq 104

These experimental devices aimed at giving, in a very short time, an idea of the behaviour of the different materials as much from the standpoint of the embrittlement as from the general corrosion phenomena.

The characteristics of these different devices are the following:

(1) Gas chamber: pressure of 350 kg/sq cm—flow rate of a few thousand cu m/day—temperature of 30° to 60° C. This installation was designed to take test samples under stress mounted on dynamometric rings, by means of which could be studied the phenomena of sulphide stress corrosion cracking (Fig 5).

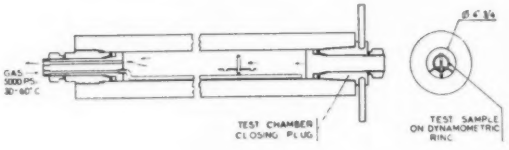

FIG 5

TEST CHAMBER FOR SAMPLES UNDER TENSION

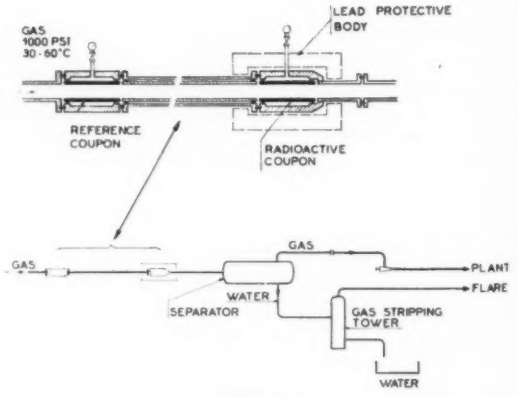

FIG 6

TEST CHAMBERS FOR RADIOACTIVE COUPONS

(2) Chamber for testing thin sheets: pressure 70 kg/sq cm—flow rate 200,000 cu m/day—temperature 30° to 60° C. In this device, composed of three independent compartments, 90 sheets of $50 \times 25 \times 2$ mm can be placed, the corrosion being measured in terms of weight loss.

(3) Chamber for measuring the corrosion on a radioactive test piece: pressure 70 kg/sq cm—flow rate 200,000 cu m/day—temperature 30° to 60° C. The test pieces were composed of tubing elements through which the gas passed. These test pieces had been previously irradiated in an atomic cell so as to mark the Fe 59. The quan-

tity of corroded iron was determined each day by analysing the radioactive water recovered at the separator situated downstream (Fig 6).

These last two chambers were designed principally to study the rate of general corrosion.

(4) Chamber for testing tubing under pressure: pressure 350 kg/sq cm—flow rate up to 200,000 cu m/day—temperature 30° to 60° C—speed of gas cu m/day—temperature 30° to 60° C—speed of gas 3 to 12 m/sec—diameter tubing $2\frac{3}{8}$ inches. The gas passes through lengths of tubing which are free at their ends; the stresses are therefore reduced to tangential tension stresses (Fig 7).

(5) Chamber for testing tubing under stress: pressure 70 kg/sq cm—flow rate up to 200,000 cu m/day—temperature 30° to 60° C—speed of gas 3 to 12 m/sec—diameter of tubing $2\frac{3}{8}$ inches. In addition to the internal pressure, a tension is applied to the ends of the tubing by means of hydraulic pistons (Fig 8).

These two testing devices for tubing were designed to study the combined effects of corrosion under stress and general corrosion.

The results of these tests are given below in tabulated form:

TABLE I

Gas Test Chamber—Testing Samples under Stress

Nature of metal	Yield strength $E_{0\cdot2}$, kg/sq mm	Tension applied in % $E_{0\cdot2}$	Plastic deformation $\frac{\Delta l}{l}$, %	Number of test samples	Maximum time of test, days	Number of test samples broken
J. 55	38	90	0	7	45	0
C. 40	35·6	90	None	3	82	0
				3	165	0
40 C. 4	49·6	90	None	3	82	None
				3	165	None
25 C.D. 4	50·9	90	None	3	82	1
				3	165	0
ASTM A. 106	22	90	None	5	82	None
Grade B	25	90	None	2	82	None
			4·8 to 5·0	3	165	None
2% Cr-1	56	90	None	7	45	0
APS 10M4	53 to 61	90	4·8 to 5·1	5	700	0
2% Cr-2	56	90	None	3	45	0
2·2 FOV	52 to 62	90	4·7 to 5·1	6	538	0
2% Cr-3	56	90	None	2	45	0
MOVP	59·0	90	None	3	165	0
	56 to 59	90	5 to 6·1	3	165	0
6% Cr-1	46·5	90	4·7 to 5·2	3	538	0
6% Cr-2	49	90	5·0	3	538	0
12% Cr-1	62·5	90	None	3	165	0
12% Cr-2	63·0	90	None	3	165	0
	61·0	90	4·8 to 5·1	3	363	3 before 363 days
12% Cr-3	56·5	90	None	3	165	0
	56·5	90	4·8 to 5	3	538	2 before 363 days
12% Cr-4	46·5	90	5 to 5·10	3	538	1 before 363 days
12% Cr-5	60	90	4·9 to 5	3	538	1 before 363 days
12% Cr-6	57	90	None	3	165	0
	61	90	5·0	3	538	0
12% Cr-7 cast	57	90	None	8	45	1 before 24 days
12% Cr-8 cast	90 to 94	90	5·1 to 5·8	2	165	1 before 2 days 1 before 10 days
	90	90	None	8	45	3 before 4 days 1 before 17 days
9% Ni	87·5	90	None	3	534	3 before 4 days
18 8	42·8	90	None	3	165	0
	35·5	90	4·7 to 5	3	538	0
23/8 Uranus 50	40 to 50	90	None	6	45	0
Monel	73	90	5·7	1	534	0
Inconel	99	90	5·1	1	534	0

These experiments confirm that the different materials employed on Lacq field stand up well to sulphide stress corrosion cracking, namely:

(1) Carbon steels having weak mechanical properties (J. 55, Grade B).

(2) Low alloy steels specially designed for Lacq (2 per cent chromium) having mechanical properties of the N. 80 grade (Cr-1, Cr-2, Cr-3).

(3) High alloy steels with improved mechanical properties (18/8–23/8).

(4) Nickel-base alloys (Monel, Inconel).

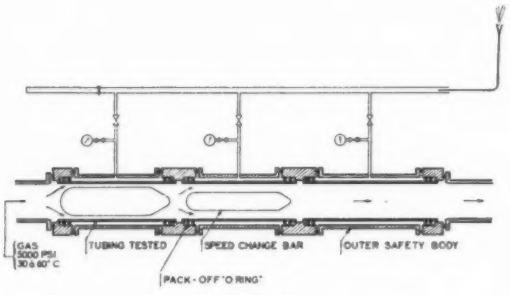

FIG 7

TEST OF TUBING UNDER PRESSURE

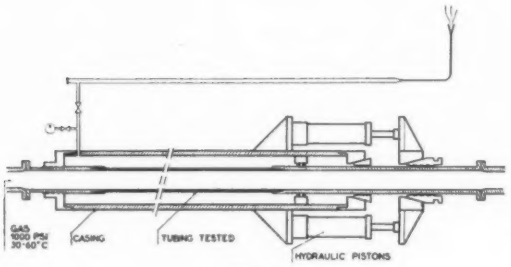

FIG 8

TEST OF TUBING IN TENSION

On the other hand, these experiments also showed that the 12 per cent Cr steel could only be employed with discernment. The 9 per cent Ni steels cannot be considered.

In these special experimental conditions in the presence of sour gas the corrosion rate is extremely slow for high alloy steels as well as for ordinary carbon steels.

The experiment carried out over a period of several months showed that the method was sufficiently accurate, but it could not be applied to this particular problem, as the greater part of the corrosion products remained adhered to the metal.

These tests, carried out on tubing under approximately the same conditions as found in the well, confirm the good behaviour of the tubing steels employed at Lacq.

Means of Detection of Corrosion of Production Equipment

To be able to follow the behaviour as regards corrosion of the different installations, it is necessary to have a means of control for measuring corrosion at any given moment and yet not to disturb production.

The most classical method consists of placing the corrosion samples in the gas stream. This method is simple but has the disadvantage of disturbing the gas stream and of giving only a rough idea of the corrosion at the point where the sample is placed. However, it was decided to use it. At special points, easily accessible in the surface installations, samples from the different equipments were placed.

In the case of the pipe, the perturbations of the gas stream can be avoided by using as samples parts of these pipes, the inspection of which is made easy by means of an appropriate by-pass system.

The measure of the iron concentration in the liquid part of the effluent does not give satisfactory information. The solubility of iron sulphide in water or gaso-

TABLE II

Tests on Thin Sheets

Nature of metal	Period of test, days	Weight loss, average in micron/year
ASTM A. 106	259	0·8
Grade B	259	0·4
2% Cr-1 APS 10M4	206	0·7
2% Cr-2 2·2 FOV	206	0·8
2% Cr-3 MOVP	206	0·5
6% Cr-1 and 2	206	0·7
12% Cr-1	206	0·10
12% Cr-2 and 3	206	0·25
12% Cr-4 and 5	206	0·15
18/8	206	0·18

TABLE III

Tests on Tubings under Pressure and Tension

Nature of steel	Longitudinal tensile stress, % of E	Transversal tensile stress, % of E	Speed of gas stream, m/sec	Period of test, years	Results
J. 55	60	—	3 to 12	2	No failure
	—	48	3 to 12	3	No failure
N. 80 reduced	—	33	3 to 12	1	No failure
2% Cr-1 APS 10M4	60	—	3 to 12	2	No failure
	—	33	3 to 12	3	No failure
2% Cr-2 2·2 FOV	—	33	3 to 12	1	No failure

line is very low, to such an extent that the greater part of the sulphide is left in suspension. In these conditions it is therefore extremely difficult to get homogeneous and representative samples.

The most appropriate control methods are those which allow the measurement, *in situ*, of the evolution of the material. The methods employed depend on the type of the equipment to be controlled. The tubings are controlled individually, on leaving the steel works, by Sonoscope, which shows up geometric faults in the metal, such as cracks or rolling marks. This control is completed by an Endoscope visual inspection. In the well the inner tubing is periodically inspected with the Otis caliper, which plots on a metal chart the location and depths of corrosion pits.

The valves are systematically and periodically controlled by gamma-ray, using a cobalt source.

The inspection of surface tubes and equipment is generally very quickly carried out by the ultrasonic method and completed, if necessary, by caesium gamma-ray.

Behaviour of Production Installations

During these two years of exploitation the corrosion has in general been unimportant, except at a few particular places in the gathering system. In this section is given a general idea of the behaviour of the different materials in contact with the gas.

The Tubings. In Table IV are reproduced the maximum performances of the tubings on 25 completed wells at Lacq field.

TABLE IV

Grade of steel	Number of tubing strings	Maximum performances of these wells			
		Length of time on production, days	Cumulative production, thousands, cu/m	Maximum daily production, thousands/cu m/day	Flow rate of gas, m/sec
APS 10M4	12	1170	244,148	736	8·70
2·2 FOV	5	470	232,246	882	10
0·8 FOV	2	0	0	0	—
MOVP	2	780	125,774	340	5·1
Chromesco vanadium	3	40	3,738	100	1·65
J. 55	1	550	386,893	1052	7·35

There have never been any tubing failures or accidents due to sulphide stress corrosion cracking.

Except in the case of one well, general corrosion is negligible.

The wells have generally been inhibited throughout their life. It has never been possible to establish an optimum inhibition rate. With a view to carrying out tests, inhibition was stopped on certain wells. On four wells inhibition was suspended for 8, 10, 12, and 14 months respectively. This experiment is being continued on two of these wells. Corrosion has proved to be negligible on the non-inhibited wells as well as on the inhibited wells, however, without it being possible to distinguish between these two cases.

The velocity of the gas stream in the tubing varies from 0 to 10 m/sec. Within this speed range the action of the gas on the metal is approximately the same. One well, however, should be particularly mentioned. In this well, which was regularly inhibited with sticks, after a period of 9 months production, *i.e.* 130 million cu m, the caliper detected an important corrosion zone situated at a depth of between 3800 and 2800 m showing a maximum pitting density at about 3500 m (Fig 9). It has not yet been possible to establish the essential reason for this corrosion; it seems, however, that it is connected with the nature of special products from the pay formation which have been carried along by the gas stream.

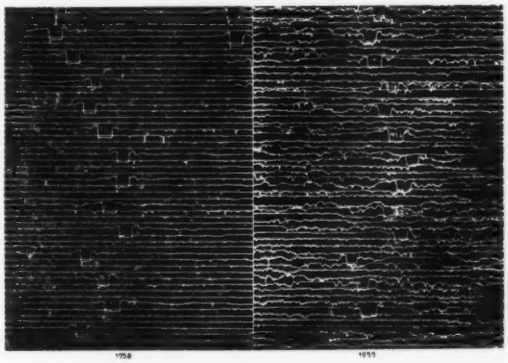

FIG 9

CALIPER CHARTS SHOWING THE AGGRAVATION OF CORROSION IN TUBING

The Valves and Chokes of the Christmas Tree. The first materials employed were made of a 12 per cent chromium steel, of the 12 Cr-7 or 12 Cr-8 type. In spite of the reaction to H_2S of this steel, proved by tests on samples, no failures have ever occurred on valves or choke bodies. Judging these steels to be unreliable, however, they were soon replaced by Uranus 50, a special steel made by La Compagnie des Forges & Ateliers de la Loire (23 per cent chromium and 8 per cent nickel, with a small addition of Mo and Cu).

Flow Line between Wellhead and Separator. No corrosion has ever been found in these pipes.

The Separators. Although certain parts of the separators are in permanent contact with water saturated with H_2S, no corrosion has been detected.

Gathering System. Downstream from the separator the mixture injected into the gathering system becomes more complex. It includes sour gas, gasoline, a little water, diethylene glycol, and an inhibitor. There has never been any embrittlement failure in this pipe. On the other hand, at certain places severe general corrosion has appeared in the form of pitting, near either the lower or upper generatrix of the pipe.

Corrosion in the lower part of the pipes was found for the first time in an elbow, closed by a blind flange placed at a slightly lower level than the rest of the pipe (Fig 10). In this elbow the water has remained

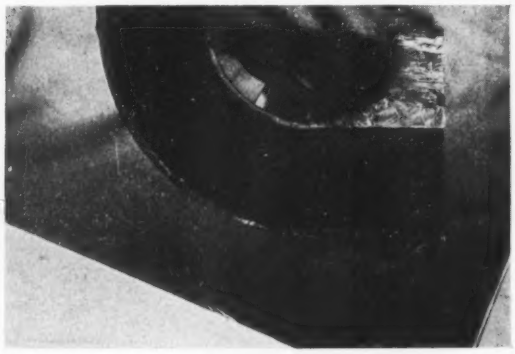

FIG 10
CORROSION FOUND IN THE LOWER PART OF AN ELBOW

for about a year in a stagnant state. During this time, pittings of 3 mm in depth have developed. This fact led us to change our inhibition formula. The inhibitor, which was only soluble in oil, was replaced by an inhibitor mixture soluble both in water and in gasoline. Since the adoption of this new formula, corrosion has nevertheless continued to develop in the zone where the water remains static and, in particular, in the little spaces between the flanges and the ring gasket (Fig 11). On the other hand, when the water is carried along in the gas stream no corrosion has been encountered even in the lower parts of the gathering system.

With regard to corrosion in the upper part of the pipe, it is only recently that this type of corrosion was discovered in a pipeline. This pipe delivers the gas from the well where pitting was found. (Fig 9.) This corrosion is found as sharp-edged pittings which join together to form large areas of corrosion (Figs 12 and 13). After a production period of nine months, certain of these pittings were 4 mm in depth. On this particular pipeline it seems that corrosion develops in the pipes where the gas stream velocity was less than 3 m/sec. In these conditions a stratified flow pattern took place. The well-inhibited aqueous and gasoline phase would protect the lower part of the pipe, whereas the gaseous phase, richer and richer in condensed water, would be all the more active as the point considered is further from the well. This problem is now being studied. We are trying to find out the causes of the corrosion and to look for an appropriate means of prevention. Generally speak-

FIG 11
CORROSION IN THE LOWER PART OF A RING GASKET

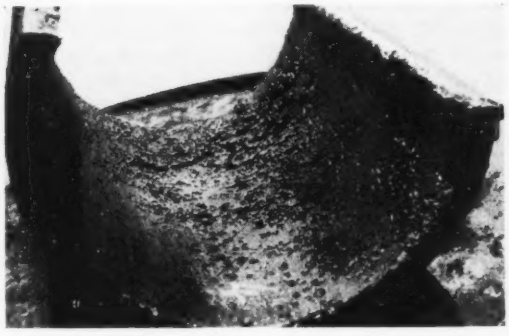

FIG 12
CORROSION LOCALIZED IN THE UPPER PART OF A 6-INCH PIPE

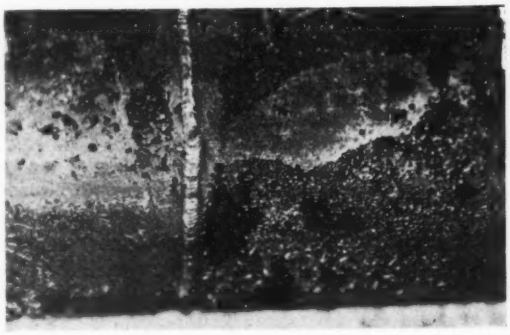

FIG 13
DETAIL OF CORROSION LOCALIZED IN THE UPPER PART OF A 6-INCH PIPE

ing, it can be suggested that the effectiveness of the normal inhibitors in the presence of H_2S is disappointing (Fig 14). In the graph is given the result of

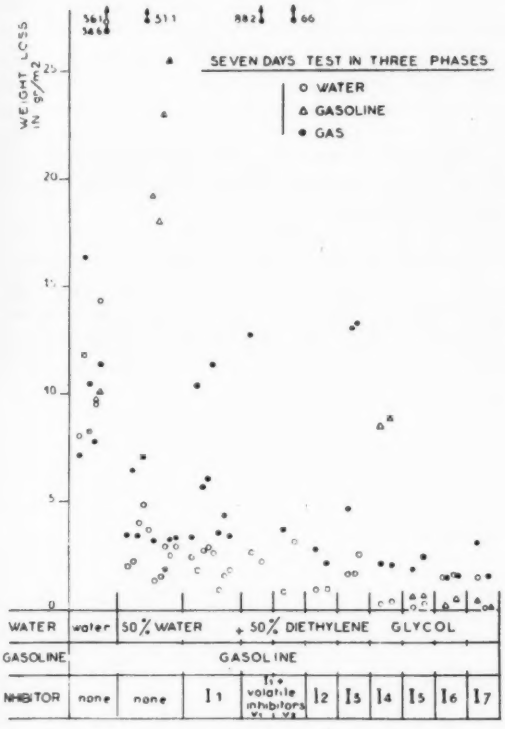

FIG 14
EFFECTIVENESS OF ORGANIC INHIBITORS IN THE PRESENCE OF LACQ GAS

laboratory tests carried out on several inhibitors. It will be observed that the DEG has a tendency to reduce corrosion in the aqueous and gaseous phases but to increase it in the gasoline phase. The inhibitor compensates the harmful effect of DEG in the gasoline phase. For the best inhibitors, corrosion undergoes a notable reduction in the aqueous and gasoline phase. On the other hand, the relative importance of corrosion remains great in the wet gaseous phase. Practical experience on the corroded pipe tends to confirm that these laboratory results are in fact optimistic.

The protection of the flow lines would seem to be effective only to the extent that the inhibited fluid could sweep the whole internal surface of the pipe.

THE EVOLUTION OF THE DESIGN OF THE INSTALLATIONS AS REGARDS CORROSION PHENOMENA

The experience of three years production, either on the experimental installations or on the wells themselves, has already led to a revision of certain exploitation designs. The tendencies of this evolution in the case of the different materials are briefly mentioned.

Tubings. Experiments were carried out in the laboratory with a view to finding a lower alloy steel, which was therefore less expensive, but which nevertheless was not susceptible to H_2S. Two new types of steel with 1 per cent chromium and small amounts of molybdenum and vanadium have already been used. These are 0·8 FOV steel of the Forges & Ateliers du Creusot and the Cromesco vanadium steel of Lorraine Escaut.

The experience of one grade, J. 55, tubing encouraged the discontinuation of the second tubing. This step was important because it permitted the increase of the diameter of the production tubing from $2\frac{3}{8}$ or $2\frac{7}{8}$ to 4 inches. The advantages of this solution were to reduce the cost of the tubing and greatly increase the production rate of the wells and thus to reduce the total number of wells drilled.

Valves and Chokes. The 12 per cent chromium steel was rejected for the manufacture of these parts. At the present time the two 4-inch master valves, the 2-inch wing valves, and the chokes are made of the 23/8 type steel.

Gathering System. As it is only recently that corrosion was found here, our ideas have not yet had time to evolve, especially as the gathering system is not quite finished. In fact, the problem at the moment is to produce with the existing gathering system and protect it from corrosion. The aggressiveness of the gas having been found severe at certain points, only one alternative remains open: either to change the glycol and inhibitor additives for other agents capable of affording a far better protection; or to dehydrate the gas as it leaves each well before entering the gathering system.

Our efforts have first of all been concentrated on the first solution. If this method proves to be unsatisfactory, dehydration methods will have to be adopted. In the near future it is easy, however, to effect notable improvements in certain respects. Chiefly, static water accumulations can be eliminated by placing the sections of the pipe which are used only intermittently at higher points. As regards the flange ring gasket assembly, the space between the flanges can be filled with special rings made of a plastic material. The elimination of corrosion in the upper part of the pipe is more difficult. It appears, however, that it is necessary to try to create a type of annular and dispersed flow which would sweep the whole pipe surface by the inhibited fluid phase.

To sum up, the materials, and utilization of the materials, now seem to be conveniently adapted to problems of sulphide stress corrosion cracking. On the other hand, means capable of eliminating general corrosion at special points have yet to be found.

GENERAL PROTECTION OF THE LACQ BURIED EQUIPMENT

Another important corrosion problem, but independent of the action of the gas, concerns the whole of the buried equipment at Lacq.

A detailed account of this complicated problem will not be given—only reference will be made.

All buried equipment is the centre of corrosion currents having either a natural origin resulting from an electrochemical disequilibrium between the metal and the ground or an outside origin connected with the proximity of installations using direct current. In certain cases the destruction of the materials may be very rapid. At Lacq the high cost of wells and pipelines has led us to look for an effective protection as quickly as possible. The method of protection to employ was all the more difficult to find because the field is crossed in an east to west direction by a main railway line fed by 1500 volts direct current.

Numerous studies have been carried out, principally in the casings. They enabled us to find a twofold solution: a special method of feeding the railway line, and the use of separate cathodic protection for the wells and pipelines.

CONCLUSION

Since the discovery of Lacq 3 in 1951, Lacq field was soon recognized, equipped, and put on production.

From the outset, difficult equipment problems were raised because of the special characteristics of the reservoir and the aggressiveness of the gas. These difficult problems were overcome by the adoption of solutions which were often original. They allowed the exploitation of the Lacq field in good conditions.

After a production period of two years, these solutions have proved satisfactory. The materials used are well adapted for the fight against sulphide stress corrosion cracking. However, a solution has not yet been found for everything, and there remains the problem of finding a means of avoiding general corrosion at special points.

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DISCUSSION

K. A. Spencer: In the early days at Lacq, when a string of pipe blew out, due to H_2S embrittlement, it was heard about all over the world and it made many people do a lot of thinking. So when this contribution was announced I was particularly interested in the author's paper, on which I must congratulate him.

In the Persian fields a piano wire was often used for putting instruments down the well, and these frequently broke due to hydrogen sulphide embrittlement. On withdrawing the wires and letting them lie in the air they used to regain their physical property of ductility. I gather that there has never been any trouble with gases high in H_2S where one side of the metal only has been exposed to air. I wonder whether that has been the experience with the very much higher H_2S contents (15 per cent) in the Lacq field. In other words, is there serious embrittlement where there is air on one side of the metal and H_2S on the other? Or is it only when it is completely immersed in high H_2S gas?

M. Estavoyer: When we use equipment on a wire line, the well is always filled with inhibited fuel. Because of this, we have never had breaks in the line, but if inhibited fuel is not used they occur very quickly. In regard to equipment, it is not thought that the fact of having air on one side would prevent the action of H_2S on the metal, *e.g.* blistering occurs on the walls of tanks containing oil with H_2S.

K. A. Spencer: I did not think it would avoid corrosion. What I had in mind was that it would reduce embrittlement or loss of shock resistance of the metal.

M. Estavoyer mentioned inhibitors. Inhibitors to my mind are something like catalysts; they seem to have become akin to the old philosopher's stone. Nobody will tell anybody else what they are using. Can the author indicate what sort of inhibitors he is generally applying?

M. Estavoyer: Generally we use only amine inhibitors.

K. A. Spencer: The author mentioned the casings of the pipes through the villages, but has any thought been given to using the new epoxy linings, applied to the pipe *in situ*?

M. Estavoyer: We have never tried to coat our gas transmission lines with epoxy resins. We have, however, used many different types in our experimental device. It was found that these resins do not resist H_2S, as blistering still occurs. Other types of coating were tested, and we were finally successful with polyurethane and silicon resins.

K. A. Spencer: Cathodic protection is mentioned rather briefly. I would like to ask which method of cathodic protection in general is used. I presume power-impressed. Is current drawn from the railway and is it supplemented by other cathodic protection? A specific point I would like to ask is what type of anode materials are used?

M. Estavoyer: We use a very simple type of anode. It is only an old drill pipe, because it is so much cheaper. It is probably not the best solution.

A. S. Plane: When I visited Lacq in 1957 Kontol sticks were being dropped down the well tubings. Is that still done?

M. Estavoyer: This is still done, but we have tried other methods. First, we did not inhibit the wells at all. Over a period of 16 months no inhibitor was used on some wells. To date, no difficulty has been experienced and we think that in the future we can dispense with inhibitors. The important question of security is always uppermost in our minds at the moment, however, and generally we continue to inhibit the wells. The second method is to wash the tubing with inhibited fuel. This is pumped down the tubing in order to coat it with the inhibitor. The question is to know for how long the inhibitors will protect the tubing. Our experience roughly coincides with that of the Americans in that two-monthly batching intervals seem to be satisfactory.

A. S. Plane: It was said, when I was there, that it was feared there would be leakage at the bottom packer on the outside of the tubing, between the tubing and the casing of the wells. This means that H_2S would leak up into the fuel oil which is used in the annulus in the wells. Have you had any experience of this?

M. Estavoyer: No such trouble has been experienced. However, should this difficulty arise, we have two means of control. First, inhibited fuel in the annulus. Secondly, the yield strength of the outer tubing is limited to 90,000 psi.

M. E. Hubbard: I too had the pleasure of visiting Lacq about two years ago, and at that time I was told that you were rather disturbed about the gas velocity in the wells, which was at that time being limited, if my memory serves me aright, to 2 m/sec. But higher velocity was being tried out in some wells, and the results would be known before long. Can you give any information on that test?

M. Estavoyer: At the beginning we limited the velocity of the gas to 3 m/sec. On some wells we produced at rates of 6 and 10 m/sec. In the case of the Lacq field, we feel there is no reason to limit velocities.

M. E. Hubbard: That is very good news, when it is borne in mind that your wells cost, I believe, something like £750,000 each to drill.

M. Estavoyer: Our original programme was for 75 wells. In view of the increased tubing sizes used and the greater velocities, 32 wells will be sufficient for a production of 20 million cu m/day.

A. S. Plane: I believe there has been trouble from stray currents with your cathodic protection, due to the fact that your railways are electrified. Has it been possible to overcome this problem?

M. Estavoyer: We have been working on this question for two years. On each well we have installed cathodic protection by impressed current. However, this is not sufficient, because of the disturbances set up by the neighbouring railway line. We now intend to use the railway line current to give an extra drainage on the well, the conductor used between the well and the railway being the gathering system. Discussions are now taking place between the railway and ourselves to obtain a negative potential on the field by modifying the Lacq sub-station.

K. A. Spencer: I presume the railway line has dc current, and that when your pipes would be positive for a short period there is a rectifier plate device to stop the current flowing.

M. Estavoyer: That is correct. In addition, we have polarized connexions between the well and the gathering system.

J. Turnbull: In a previous question on wire line work, the author mentioned that he overcame the problem of corrosion of a wire line by filling the tubing with fuel oil, I think. If one is running a storm choke, a tool that is intended to be left at the bottom of the well, this presents no problem; but if one intends running a pressure gauge, or any similar tool, for operation at various depths, possibly under flowing conditions, then surely the wire must be inhibited against the gas. One can obviously run in with fuel oil in place, but this must be displaced at some stage. Has the author in fact experienced this sort of thing?

M. Estavoyer: We never try to record pressures and temperatures in the wells under flowing conditions by using carbon steel wire lines. On one occasion we did successfully record these using a stainless steel line.

— **Carval:** Generally, we fill the tubing with inhibited oil and run the pressure gauge to the bottom of the well where it is left in the tail pipe. The wire line is then pulled out and the fuel oil evacuated. A back pressure test is then made for a period of several days. After recording, the well is then refilled with fuel oil and the pressure gauge is recovered.

A. Chatting: I would like to ask if the above-ground piping systems at Lacq are earth-bonded and have electrical continuity.

M. Estavoyer: The pipes are not earth-bonded, but they have electrical continuity.

A. Chatting: I was thinking that with a high velocity flow of gas one could get static electricity forming and one might, therefore, want to earth-connect all sections of the pipe.

M. Estavoyer: Static electricity has never been measured, as this phenomenon never gives us any trouble.

M. E. Hubbard: I do not think we ought to let this meeting finish without stressing our admiration of the courage required to open up the Lacq fields. M. Estavoyer has been very discreet in the figures he gave and did not point out that it is the highest gas pressure field that has ever been discovered, and probably about the most corrosive. They started what was to France a completely new industry, faced problems that had never been met before, and won through triumphantly. May I, as one who has worked many years in France, congratulate French industry on its success.

The meeting then closed with a hearty vote of thanks to the speaker.

THE USE OF OZONOLYSIS IN OIL CONSTITUTION RESEARCH. II.* SIDE-CHAIN ANALYSIS OF AROMATICS AND BENZOTHIOPHENES FROM VARIOUS OIL FRACTIONS†

By H. BOER‡

SUMMARY

An ozonolytical method for determining side chains in aromatic molecules has been applied to a variety of straight-run distillates, catalytic reformates, and aromatics obtained by hydrodesulphurization of benzothiophenes.

The distribution of side chains in aromatics from straight-run gasoline fractions of widely varying crudes turns out to be quite similar: in all cases 70–80 per cent of the substituents are methyl groups, 10–20 per cent ethyl groups, and 0–10 per cent propyl and butyl groups. Comparable group distributions are found for catalytic reformates.

Benzothiophenes occurring in straight-run gas-oil fractions (bp 290°–325° C) were found to be substituted most frequently in the 2-position.

INTRODUCTION

In a previous paper [1] the author described an ozonolytical method for side-chain analysis of monoaromatics occurring in petroleum fractions. The method involves the addition of ozone to the aromatic "double bonds," catalytic hydrogenolysis of the ozonides, and oxidative cleavage by hydrogen peroxide of the diketones thus obtained to yield fatty acids. The alkyl groups of these fatty acids represent the side chains originally present in the aromatic nucleus. The fatty-acid mixture is analysed by gas–liquid chromatography.§

The quantitative application of the method was based on experiments with model hydrocarbons, from which empirical correction factors were derived; these were checked on synthetic mixtures of known composition. This procedure was necessary because even though our fatty-acid yields are considerably higher than those quoted in the literature (*e.g.* 20–25 per cent as diketones [2]), they do not exceed some 70 per cent.

In this paper some more results on petroleum fractions are presented, whilst the method has also been applied to catalytic reformates.

In the course of our work on selective reduction [3a,3b] it was found that benzothiophenes could be isolated from accompanying aromatic hydrocarbons in the same boiling range by reaction with calcium hexammine. The thiols thus formed can be quantitatively converted into the corresponding alkylbenzenes. Consequently, ozonolytic analysis of these alkylbenzenes constitutes a novel approach to determining the structures of the original benzothiophenes.

RESULTS AND DISCUSSION

1. *Gasoline Fractions*

In Table I the results on monoaromatic fractions from various straight-run gasolines are given, together with previously published data on a Venezuelan crude.[1]

It is seen that by far the most important substituent is the methyl group, constituting 70–80 per cent of the side chains; 10–20 per cent of the side chains consist of ethyl groups, while the propyl and butyl groups together contribute some 5–10 per cent. As regards side-chains distribution in these aromatics, apparently there are only small differences between the various crudes.

2. *Catalytic Reformates*

The results of the analysis of the aromatics from two catalytic reformates are presented in Table III. These two fractions, a normal and a high-severity reformate from the same feed, contained 56 and 61 per cent of aromatics, respectively; for the analysis the aromatics were concentrated by displacement chromatography. Since the distribution of the substituents is similar, the extra 5 per cent wt of aromatics in the high-severity reformate do not seem to differ radically in average size of side chains as compared to the normal reformate. A striking fact is the absence of the *iso*propyl group in the high-severity reformate, probably a result of the more severe reforming conditions.

The third example of Table III refers to a higher boiling catalytic reformate fraction, which by deutera-

* As Part I is denoted Boer, H. *Proc. 4th World Petrol. Congr.*, 1955, **5**, 1–12.

† MS received 15 February 1960.

‡ Koninklijke/Shell-Laboratorium, Amsterdam (Shell Internationale Research Maatschappij N.V.)

§ Gas–liquid chromatography of the corresponding methyl esters—prepared by reaction with diazomethane—is more convenient.[6]

TABLE I

Side-Chain Analysis of Monoaromatic Fractions from Various Gasolines

(For the composition of these gasolines see Table II)

Aromatics originating from	Boiling range	Mol wt *	Mol % side chains (including CH_{ar})							Mol % side chains (excluding CH_{ar})					
			CH_{ar}	C_1	C_2	n-C_3	i-C_3	n-C_4	i-C_4 + *sec*-C_4	C_1	C_2	n-C_3	i-C_3	n-C_4	i-C_4 + *sec*-C_4
Venezuelan crude	150–165	118	62·0	29·2	7·9	0·9	0·0	0·0	0·0	76·8	20·8	2·4	0·0	0·0	0·0
	165–185	125	58·3	31·4	6·1	2·6	1·5	0·0	0·0	75·4	14·7	6·2	3·6	0·0	0·0
	185–195	137	49·3	36·2	9·5	3·1	1·8	0·0	0·0	71·4	18·8	6·1	3·6	0·0	0·0
Indonesian crude II	150–165	122·0	62·0	31·2	5·0	0·9	0·4	0·5	0·0	82·2	13·2	2·4	1·1	1·3	0·0
	165–185	133·0	65·8	26·2	4·4	2·1	0·9	0·2	0·4	76·7	12·9	6·1	2·6	0·6	1·2
	185–205	143·4	44·8	45·3	6·3	1·7	0·7	0·4	0·8	82·2	11·4	3·1	1·3	0·7	1·4
Middle East crude	150–165	121·3	63·0	30·6	6·2	0·2	0·0	0·0	0·0	82·7	16·8	0·5	0·0	0·0	0·0
	165–185	135·8	67·0	25·1	5·5	1·5	0·9	0·0	0·0	76·1	16·7	4·5	2·7	0·0	0·0
	185–205	145·5	55·2	30·8	7·6	3·4	1·0	1·2	0·8	68·7	17·0	7·6	2·2	2·7	1·8
Indonesian crude III	150–165	124·6	66·7	27·9	4·3	0·7	0·4	0·0	0·0	83·8	12·9	2·1	1·2	0·0	0·0
	165–185	128·5	56·2	36·8	6·2	0·8	0·0	0·0	0·0	83·9	14·2	1·8	0·0	0·0	0·0
Pennsylvanian crude	150–165	118·8	58·7	34·5	6·3	0·5	0·0	0·0	0·0	83·5	15·3	1·2	0·0	0·0	0·0
	165–185	120·7	53·5	41·1	3·7	0·8	0·9	0·0	0·0	88·4	8·0	1·7	1·9	0·0	0·0
	185–205	138·8	44·0	44·2	7·8	1·9	1·2	0·0	0·8	79·0	14·0	3·4	2·2	0·0	1·4

* Micro Victor Meyer.

TABLE II

Distillation Data of Gasolines

(Vigreux still, 20 theoretical plates)

Starting material	Weight per cent fractions with boiling range, ° C, at 760 mm							
	<150	150–165	165–185	185–205	205–225	225–245	Residue	Loss
Pennsylvanian tops, 55°/760 mm–142°/40 mm	54·8	10·7	13·4	9·6	6·1	2·4	2·4	0·6
Indonesian II tops, 96°/760 mm–156°/50 mm	35·9	13·9	18·2	14·2	7·5	5·4	5·4	0·8
Indonesian III tops, 71°/30 mm–181°/30 mm	0·5	2·3	7·8	10·7	12·1	15·0	<297°: 39·3 >297°: 1·3	2·0
Middle East full range gasoline	55·8	7·8	11·2	11·2	9·3	1·5	2·8	0·4

TABLE III

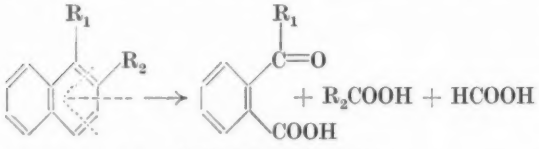
Side-Chain Analysis of Middle East Catalytic Reformates

Aromatics originating from	Boiling range	Mol wt *	CH_{ar}	Mol % side chains (including CH_{ar})						Mol % side chains (excluding CH_{ar})					
				C_1	C_2	n-C_3	i-C_3	n-C_4	i-C_4 + *sec*-C_4	C_1	C_2	n-C_3	i-C_3	n-C_4	i-C_4 + *sec*-C_4
Normal reformate	Ex 93–205	114·5	63·8	30·6	3·8	0·8	0·9	0·0	0·0	84·5	10·5	2·2	2·5	0·0	0·0
High-severity reformate	Ex 93–205	113·5	64·8	29·6	4·1	1·4	0·0	0·0	0·0	84·2	11·7	4·0	0·0	0·0	0·0
Reformate	200–284	142·5	—	—	—	—	—	—	—	74·3	16·7	6·9	0·0	2·0	0·0

* Micro Victor Meyer.

tion and mass spectrometric analysis [4] was shown to contain about 50 per cent benzenes, 25 per cent naphthenobenzenes, and 25 per cent naphthalenes. Of the latter about 15 per cent were substituted.

It is to be expected [5] that under our reaction conditions only *one* (the highest-substituted) ring of the alkylnaphthalenes will be attacked, and that only the alkyl substituents attached to positions 2 and 3 of the attacked ring will be converted into volatile carboxylic acids. In view of the low molecular weight of the naphthalenes under consideration (max C_{12}) and the relatively small amount of these compounds, it is felt that this will cause only a small deviation in the overall substitution figures found, and mainly in the percentage of methyl groups. The reaction scheme may be represented as follows:

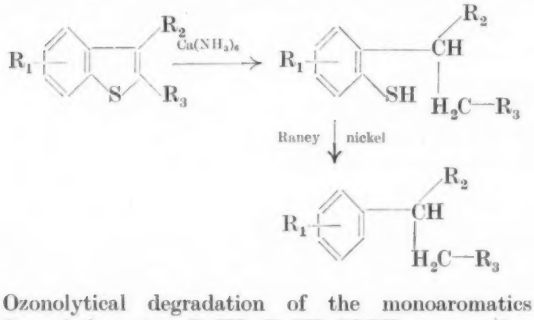


– – – – – – – – scission effected by ozone
— — — — — — subsequent scission effected by hydrogen peroxide

It is obvious that with naphthenoaromatics, none of the substituents present in the saturated ring are found by this analysis.

3. *Benzothiophenes*

The conversion of benzothiophenes into monoaromatics mentioned in the introduction takes place according to the following reaction scheme:



Ozonolytical degradation of the monoaromatics formed then gives R_3CH_2–R_2CH–COOH among other compounds. This analysis must give much higher figures for the relative amounts of longer side chains if analogous alkyl substitution patterns obtain for benzothiophenes and aromatic hydrocarbons in gasolines. This is confirmed by the data of Table IV. In the case of the 292°–296° C fraction the thiols formed by reaction with calcium hexammine were first extracted with an aqueous solution and then with a methanolic solution of potassium hydroxide. These two samples were then treated with Raney nickel and analysed separately. The thiols originating from the 300°–325° C fraction were extracted with methanolic potassium hydroxide only.

TABLE IV

Side-Chain Analysis of Monoaromatics from $Ca(NH_3)_6$*-Treated Diaromatic Fractions from a Venezuelan Crude*

Boiling range of original diaromatic fraction	Mol % side chains [a]					
	C_1	C_2	*n*-C_3	*i*-C_3	*n*-C_4	*sec*-C_4
300°–325° C, extraction with KOH–CH_3OH . .	58·5	13·8	13·1	4·2	5·9	4·5
292°–296° C, extraction with KOH–H_2O . . .	59·7	18·2	8·1	—	4·7	9·3
292°–296° C, subsequent extraction with KOH–CH_3OH . . .	59·3	14·3	11·5	3·1	4·7	7·1

[a] Exclusive of CH_{ar}.

Whilst the values for *iso*propyl are comparable with those for higher-boiling aromatics from gasoline, the values for *n*-propyl are considerably higher. This indicates that methyl substitution at position 2 in the benzothiophenes is favoured.

No other C_5-acids than those corresponding to the C_4 groups mentioned in Table IV were found. Hence it follows that geminate-substituted 2,3-dihydrobenzothiophenes are absent in the products analysed, as these would have given rise [3b] to trimethylacetic acid (pivalic acid) and/or 3-methylbutanoic acid (isovaleric acid).

ACKNOWLEDGMENT

Thanks are due to Miss J. H. E. Chevalier and H. van Kranen for their valuable assistance in the experimental work.

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THE STRESS DEPENDENCE OF THE SOFTENING TEMPERATURES OF BITUMINOUS COMPOUNDS *

By T. HOLT †

INTRODUCTION

DURING the evaluation of certain bituminous compounds under simulated service conditions it was found that the compounds softened at temperatures appreciably below those predicted by measurements obtained by the ring and ball technique.[1] An examination of the experimental conditions revealed that the stresses to which the bitumen had been subjected were greater than those which it experiences during the ring and ball measurement. Accordingly, it was decided to examine the effects of stress variation on the softening temperatures of certain bituminous compounds, and the results are described herein.

EXPERIMENTAL

The ring and ball technique does not readily lend itself to variations in stress, but a similar method, the Krämer–Sarnow,[2] uses a column of mercury of known weight (5 g), in a glass tube of standard dimensions, as the load in contact with the compound. The bitumen is contained in a metallic ring, similar to, but smaller than that employed in the ring and ball apparatus. The temperature at which the bitumen will no longer support the mercury is taken as the softening temperature. By varying the load, the softening temperature of the bitumen under varying stresses can readily be determined.

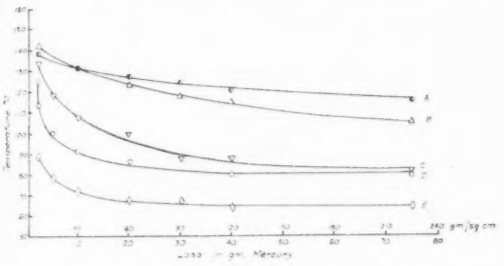

FIG 1

SOFTENING TEMPERATURE/LOAD CURVES FOR BITUMINOUS COMPOUNDS

Fig 1 illustrates the effect of stress variation on the apparent softening temperatures of several bituminous compounds whose formulations are given in Table I. For the purpose of comparison, the softening temperatures determined by the ring and ball method are also given, together with values interpolated from the Krämer–Sarnow method for the stress comparable to that of the ring and ball, namely, *ca* 5 g/sq cm. Single values at high stress are also included to show the marked difference.

TABLE I

Compositions of Bituminous Compounds and Measured Softening Temperatures

Compound	Composition	Ring and ball softening temp, °C	Interpolated values at ring and ball stress (K.–S.), °C	Softening temp at 5 g load (K.–S.), °C	Softening temp at 70 g load (210 g/sq cm) (K.–S.), °C
A	Mexphalte R135/10 + 18% Acrawax C	135	137	133	117
B	Mexphalte R135/10	138	141	136	106
C	Mexphalte 10/20 + 16% Acrawax C	127	132	119	82
D	Experimental compound as in E but partially oxidized	100	105	98	80
E	Experimental compound based on Gilsonite + drying oil	82	89	79	64

RESULTS AND DISCUSSION

Two important features are observable in the results illustrated by the curves in Fig 1.

1. The marked dependence of the measured softening temperature on the stress at comparatively low stresses, particularly in the stress region normally experienced by the bitumen in the ring and ball determination. The effect becomes less marked when very high softening points are encountered, *e.g.* compounds A and B.

2. The tendency for the curve to level out to a comparatively constant softening temperature over a range of high applied stresses.

CONCLUSION

It is evident from the results described that extremely misleading information regarding the softening temperature of a bituminous compound can be obtained by using the ring and ball method of measurement. The Krämer–Sarnow method can be used to obtain more reliable information, but here it is recommended that the softening temperature over a range of loads be used in place of a single 5-g determination, for this too falls in the critical range. Should this be inconvenient, single load values determined at higher stresses will be more reliable than the ring and ball measurement.

ACKNOWLEDGMENT

The author wishes to thank Sir Willis Jackson, F.R.S., Director of Research and Education, Associated Electrical Industries (Manchester) Ltd, for permission to publish.

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* MS received 3 March 1960

† Associated Electrical Industries (Manchester) Ltd.

OBITUARIES

ARTHUR LLOYD EASTLAKE

1894–1960

ARTHUR LLOYD EASTLAKE, who died in Chicago early in April at the age of 65, was one of the early members of the Institute, having been elected a Student Member in 1914. He was transferred to Associate Member in 1920 and remained in that category until at a later date his activities took him out of the petroleum industry. He subsequently came back to the industry and rejoined the Institute as an Associate Fellow in 1950.

His first contact with the petroleum industry was during the period 1911–15, when he was an articled pupil with Messrs W. J. Fraser & Co. Ltd at Dagenham. Then followed a short period as an assistant engineer with the Anglo-Persian Oil Company until he took a commission in the Royal Engineers for service during the first world war. Part of his service was spent in the Special Brigade, and he was engaged on work in connexion with flame warfare. He was, in fact, the only military officer on board H.M.S. *Vindictive* during the Zeebrugge raid, and was in charge of the flame-throwing apparatus.

After the war, Lloyd Eastlake joined Vickers Ltd as a research engineer on oil process development, and in 1924 returned to the Anglo-Persian as an assistant engineer in South Wales and in France. In 1926 he left oil to set up his own business in motor engineering, and in 1930, after a short period as maintenance engineer at the Lake Shore Mines, Northern Ontario, he joined the Sinclair Refining Company as assistant to the chief engineer in their engine laboratories in East Chicago, U.S.A. From 1937 until 1946 he was engineer in the Aeronautical Inspection Directorate of the MAP, and then spent three years in the Transcona motive power plant of the Canadian National Railways. In 1949 he returned to the Sinclair Refining Company at their Research and Development Department, Harvey, Illinois.

Lloyd Eastlake, who was the only son of Arthur W. Eastlake, co-founder of the Institute, was a likeable man. Although his visits to Britain were few and far between, it was always a pleasure to see him and to reminisce.

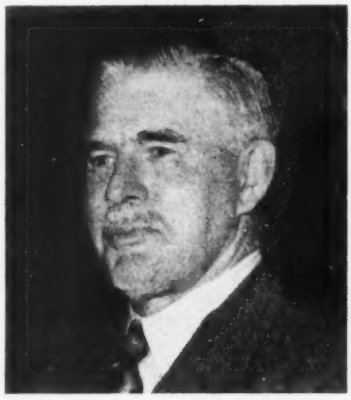
G. S.

LAUNCELOT OWEN, M.C., A.R.C.S., A.R.S.M., D.I.C.

1888–1960

IT is with regret that we record that Launcelot Owen, a member of the Institute since 1915, was a passenger in an aircraft reported missing during a journey from Australia to Timor early in February.

His first contact with petroleum was in 1911, when, after taking his Associateship of the Royal College of Science, he became an analyst with the Pacific Phosphate Company and carried out examinations of lubricating and fuel oils. Later he entered the Royal School of Mines and took his A.R.S.M. in oil technology and geology in 1919. Two years later he received his Diploma of the Imperial College.



From then on he was fully occupied with the geology and search for petroleum, and for a considerable period was working on these problems in Colombia. Venezuela was also one of the countries which came into his purview, and for several years he was senior geologist to British Controlled Oilfields Ltd. He also spent two years in Turkey and Saudi Arabia.

He went to Australia in 1937, and for three years was with the Papuan Apinaipi Petroleum Company as geologist. From 1940 he served during the war period as chief instructor in the Tactical School Engineering Wing of the Australian Military Forces.

From 1944 until his retirement in 1959 he was technical secretary to the Power Group of the Standards Association of Australia.

He was intending to return to England early this year, but a request to visit Portuguese Timor to, as he himself wrote, "carry out research on the manner and direction of the migration of petroleum," necessitated a postponement of his return.

"Taffy," as he was fondly known by his many friends, was a kindly and happy character, with definite opinions on oil matters and a forthright manner. He will be missed by many, and the sympathy of all will go to his widow.

G. S.